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Reaction of Elite Faba Bean Genotypes for Soil Acidity Stress

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Abstract— *Soil acidity is one of the major abiotic stresses in Ethiopian highland agriculture that limits crop production in general and a prime factor of faba bean production in particular. The goal of this study was to investigate the effect of soil acidity stress on grain yield of 50 faba bean genotypes of which 22 were released varieties. The experiment was comprised two stress levels (lime treated and untreated) arranged in randomized complete block design with three replications. The analysis of variance for both potential yield (YP) and stress yield (YS) indicated significant differences among fifty genotypes. Also, significant differences were observed among faba bean genotypes regarding seven soil acidity stress indices. Based on the YP, the genotypes Moti, CS20DK, EKLS/CSR02010-4-3, Cool-0024 and EH07023-3, had the highest yield under non-stressed condition, while the genotypes CS20DK, Obse, Wolki, Didi'a and Dosha displayed the highest yield under stressed condition. In terms of grain yield (g/5plants) CS20DK was ranked 2nd and 1st with 113.24g and 79.56g under non-stressed and stressed, respectively. However, based on the overall performances of multiple stress indices (YI, STI, MP, GMP, HM, SSI and RYR) Wolki, Dosha and Obse were confirmed as soil acidity stress tolerant genotypes whereas Wayu was identified as the most sensitive genotype. The STI, MP, GMP and HM indices exhibited strong correlation with YP, while YI showed strong correlation with YS indicating YS can discriminate soil acidity tolerant genotypes with high grain yield under stress conditions. Hence, use of multiple stress indices confirms the performance consistency of the genotypes considered for the stress.*

Keywords— ***Grain yield, Soil acidity stress, Soil acidity tolerance, Lime treated, Lime untreated.***

I. INTRODUCTION

Soil acidity is one of the major production limiting factors of faba bean in Ethiopia [1]. It covers 43% of the arable lands of which strong soil acidity covers 28.1% of the entire country [2]. Soil acidity is associated with low nutrient availability and it is a major yield-limiting factor for bean production [3]. It affects agricultural producers in tropical and subtropical regions by limiting legume productivity [4]. In the highlands of Ethiopia, the rainfall intensity leaches substantial amounts of exchangeable bases results low organic matter and nutrient availability [5]. Faba bean is sensitive to soil acidity [6]. Hence, faba bean yield was reduced in acid soils due to low P availability and deficiency of Ca and Mg or toxicity of Al, Fe and Mn [7].

Soil pH of 4.49 to 4.94 are measured from soil samples from three locations (Holetta, Watebecha Minjaro and Jeldu) of central Ethiopia which is considered as strongly acid (pH< 5.5) [8]. The use of lime is a potential option for sustainable management for restoring soil health and fertility. It is an effective and widespread practice to improve crop yields on acid soils and it make the soil environment better for leguminous plants and associated microorganisms [9]. The effect of Al^{3+} toxicity is ameliorated by the application of P-containing fertilizers [10]. However, some of these options are less effective if cultivars are sensitive to acid soil and either not available to farmers or farmers are poor to purchase the materials [11]. Acid tolerant crop varieties reduce the amounts of lime required [12]. Lime application was significantly

increase grain yield of faba bean on acid soils of western highlands of Ethiopia [13]. Faba bean varieties released so far in Ethiopia were not tested and recommended for areas with soil acidity stress.

The use of acid tolerant varieties remains the first option and low cost if the use of lime is beyond the reach of smallholder farmers. Study on soil acidity problems and response to lime application have been done in some part of the country. However, information on soil acidity stress tolerance level of genotypes based on stress indices was scanty. Therefore, identifying the best performing genotype under acid soil stresses and non-stress environments is of a paramount importance for breeding faba bean genotypes adaptable to acidic soils. Hence, this study was initiated with the objectives (i) to identify soil acidity tolerant faba bean genotype(s) under stressed (no lime) and non-stressed (limed) condition and (ii) to know the interrelationships among the evaluated stress indices.

II. MATERIALS AND METHODS

2.1 Description of testing locations

The experiment was conducted during 2017 main cropping season under rain fed condition at three locations Holetta, Watabecha Minjaro and Jeldu. Holetta agricultural research center is located at 09^0 00'N, 38^0 30'E at an altitude of 2400m above sea level. It is 29 km away from Addis Ababa on the road to Ambo and characterized with annual rainfall of 1072 mm, mean relative humidity of 58.8%, and mean maximum and minimum temperature of 24.1^0C and 6.6^0C, respectively. The soil of the center is Nitisol characterized with pH 4.66. Watabecha Minjaro is located at 09^0 05' 55" N, 38^0 36' 21" E, and altitude 2565 meter above sea level in the central highlands of Ethiopia. The site is typically characterized by flat plains with cool subtropical climate. Annually receives about 1100 mm rainfall. The mean maximum and mean minimum temperatures are 23.3°C and 8.7°C, respectively. The soils is categorized as Nitisols with deep red and well-drained tropical soil having a pH range of 4.5 to 5.5, contain low organic matter (<20 g kg-1) and low nutrient availability [14]. Jeldu sub- station is one of the cool season crops trial sites which is located at an altitude of 2800m above sea level at 09^0 16'N and 38^0 05'E. It receives average annual rain fall of 1200 mm with an average annual maximum and minimum temperature of 16.9^0C and 2.06^0C respectively [15]. The area has a soil pH of 4.49.

2.2 Experimental materials and design

A total of 50 faba bean genotypes were used in the study: 22 released varieties and 28 pipe line genotypes. Additionally, quick limestone (CaO) a product of Derba Cement Factory collected from Holetta agricultural research center was used. The experiment was arranged in randomized complete block design with three replications using adjacent block technique (growing the two sets adjacent to each other). Each block was divided into two adjacent sub-blocks to accommodate both with and without lime plots. The spacing between adjacent and within blocks were 1.5 and 2m, respectively. The experimental plots consisted of one row of 4m length and 40cm row spacing continuously and 10cm between plants ($1.6m^2$). Undamaged clean seeds of each genotype were selected to a reasonably uniform size by hand sorting and whole set of genotypes were planted separately in alternating adjacent sub-blocks with and without lime in side-by-side pairs. One sub-block in each block was limed and not to the other sub-block. Blended Fertilizer was applied at the rate of 19 kg N, 38 kg P_2O_5 and 7 SO_4 in the form of NPS (121kg/ha) that can substitute DAP in each area during planting. One faba bean variety (Dosha) was planted as a border row in each block to avoid border effect. The other agronomic practices were carried out uniformly to all genotypes as per the recommendations made by the national research system for faba bean. Five random faba bean plants in each row were used for data collection to determine yield and yield components.

Soil sampling, preparation and analysis

Prior to planting, ten surface soil samples (20 cm depth) were taken randomly from representative spots of the entire experimental field using an auger and composited to one representative sample. The composite sample was air-dried at room temperature, thoroughly mixed and ground to pass through a 2mm sieve and then analyzed for: particle size distribution (soil texture), pH, organic carbon, cation exchange capacity, exchangeable bases (Na, K, Ca and Mg), total nitrogen, available Phosphorus, exchangeable acidity, extractable aluminum and micro nutrients (Zn, Fe, Mn and Cu). One soil sample for bulk density analysis at each location was taken by core sampler. Moreover, after harvesting, surface soil samples 0-20 cm were collected randomly from five spots in each lime treated blocks and analyzed to know the level of increment in parameters analyzed before planting with the exception of soil texture and bulk density.

Soil bulk density was determined using a core sampler and soil pH was determined by potentiometric method at 1:2.5 soils: water ratio [16]. Cation exchange capacity was determined by 1M ammonium acetate method at pH 7 [17] whereas organic carbon was determined by the Walkley and Black method [18] and total nitrogen by the micro-Kjeldhal method [19], available P was determined by the Olsen method [20]. Soil particle size distribution was determined by the hydrometer method [21]. Exchangeable

Na, K, Mg and Ca were determined by Ammonium acete-AAS method and extractable Al, Fe, Zn, Mn and Cu by DTPA-AAS method. Analysis of all the soil parameters was done at Holetta agricultural research center soil and plant analysis laboratory.

Table 1: Description of 50 faba bean genotypes used in the study

No	Genotypes	No	Genotypes	No	Genotypes
1	Cool-0030	18	Dosha¥	35	Cool-0035
2	Wolki¥	19	Gora¥	36	KUSE2-27-33
3	EKLS/CSR02012-2-3	20	EH08035-1	37	EH07015-7
4	Obse¥	21	Wayu¥	38	Cool-0024
5	NC58¥	22	EKLS/CSR02023-2-1	39	Selale¥
6	Ashebeka¥	23	Mesay¥	40	Moti¥
7	Hachalu¥	24	EH09004-2	41	EH06027-2
8	Degaga¥	25	EH06088-6	42	EKLS/CSR02019-2-4
9	EH09031-4	26	EKLS/CSR02017-3-4	43	EH09002-1
10	Holetta-2¥	27	Kasa¥	44	Tumsa¥
11	EH09007-4	28	Cool-0025	45	Gebelcho¥
12	EH07023-3	29	EH06070-3	46	EK05037-5
13	EK05006-3	30	EKLS/CSR02010-4-3	47	Didi'a¥
14	EKLS/CSR02014-2-4	31	Cool-0031	48	Cool-0034
15	Numan¥	32	Cool-0018	49	CS20DK¥
16	Bulga 70¥	33	EKLS/CSR02028-1-1	50	Tesfa¥
17	EK05001-1	34	EK 05037-4		

¥ = Released cultivars

2.3 Lime rate determination and application

Lime rate (LR) was determined based on the soil laboratory analysis results and applied uniformly on the lime treated blocks one month ahead of planting. The amount of lime applied was determined using the exchangeable acidity, bulk density of the soil as well soil depth (Plough depth) and area of the experimental plot based on the equation presented below [22].

$$LR\left(\mathrm{CaO}\left(\frac{\mathrm{kg}}{\mathrm{ha}}\right)\right) = \frac{\mathrm{EA}\left(\frac{\mathrm{cmol}}{\mathrm{kgsoil}}\right) * \mathrm{DS(m)} * \mathrm{A(m^2)} * \rho b\left(\frac{g}{cm^3}\right)}{2} * LF$$

Where: LR= Lime rate; EA= Exchangeable acidity; DS= Depth of soil; A= Area of land; ρb = Bulk density; LF= Liming factor/adjustment factor (LF= 2, for faba bean) and depends on crop response.

Data collection

Data on grain yield for each genotype was taken on 5 plants for both lime treated (YP) and lime untreated plots (YS). Data for soil acidity stress indices were calculated based the yield variation due to soil acidity stress in lime untreated plots relative to the respective lime treated plots. These traits were used to evaluate the sensitivity of tested genotypes in the absence of lime treatment at all test locations using soil acidity stress indices as suggested by the different authors (Table 2).

Table 2: List of stress indices

Stress index	Formula	Reference
Relative yield reduction	1-(YS/YP)	[23]
Stress tolerance index	(YP x YS)/ µYS	[24,25]
Stress susceptibility index	$\frac{YP-YS}{YP\times(1-\left[\frac{\mu YS}{\mu YP}\right])}$	[24, 25]
Mean productivity	(YP+ YS)/2	[26]
Geometric mean productivity	(YS × YP)½	[24]
Harmonic mean	2(YP-YS)/(YP+YS)	[24]
Yield index	YS/µYS	[27]

Where, YP = grain yield from lime treated plot of a given genotype, YS = grain yield from lime untreated plot of the same genotype, µYS = mean grain yield of all lime untreated plots, µYP = mean grain yield of all lime treated plots, µ = mean

2.4 Data Analysis

2.4.1 Analysis of variance

The SAS computer package version 9.3 statistical software [28] was used to test for presence of outliers and normality of residuals. All indices data were subjected to analysis of variance (ANOVA) for RCBD as per the procedure indicated by [29]. The SAS GLM (General Linear Model) procedure was employed for the analysis of variance. Existence of significant difference among the genotypes, locations, management level and their interaction were determined using the F-test in all the cases. Mean separation at 1% or 5% probability levels were done using Duncan's Multiple Range Test (DMRT) following [29], whenever genotype differences were significant.

III. RESULTS AND DISCUSSION

3.1 Soil phsico-chemical properties of test locations

The soils results from the three test locations showed very strong acidic condition < 5 (Table 3) because soil pH below 5.5 considered as strongly acid, 5.6 to 6.5 are moderately acid and 6.6 to 7.3 are neutral; [8]. Little modification of pH at each location in the lime treated blocks were observed indicating that lime improves the chemical properties of soils needs more time to bring to the required change. Lime is slow acting and significant increase in grain yield compared to the control expected in the next planting season [12]. Generally, applying calcium containing lime materials improve nutrient availability, particularly phosphorus; through reduction of phosphorus fixation thereby improving soil pH where maximum availability of the nutrient may be obtained. The result agrees with the reports of Abebe and Tolera [13].

Table 3: Results of soil chemical analysis before and after lime treatment at three locations

Parameter	Holetta		Watebecha Minjaro		Jeldu	
	Before lime	After lime	Before lime	After lime	Before lime	After lime
pH	4.66	5.03	4.94	5.08	4.49	4.80
Avail. P	7.96	9.57	12.74	12.74	13.17	15.14
CEC	18.18	19.04	17.38	18.80	20.24	20.42
Ex.K (ppm)	0.57	0.58	0.53	0.54	0.14	0.23
Ex.Mg (ppm)	2.35	2.46	1.25	1.26	0.50	0.58
Ex.Ca (ppm)	9.43	10.89	9.30	10.95	6.35	11.82
Ex. Al (PPm)	0.49	0.28	0.55	0.33	2.39	0.85
Mn (ppm)	48.58	47.76	37.97	30.16	58.23	50.45
Cu (ppm)	4.07	3.92	3.70	3.12	4.95	3.85
Ext.Fe (ppm)	180.77	164.45	245.70	231.07	341.13	327.43

Ext.Zn (ppm)	0.83	0.68	1.15	1.10	4.42	2.67
Ex. Acidity	1.01	0.61	0.98	0.62	3.36	1.30

CEC= cation exchange capacity, Ex. = exchangeable, Ext=extractable

3.2 Analysis of variance

The combined analysis of variance over three locations for soil acidity stress indices showed the presence of significant differences among genotypes for all indices and location. The interaction of genotype by location had also significant influence on the stress indices of genotypes (Table 4). The result indicated that the genotypes were performed differently in different locations. Previously [30] reported that variation of stress tolerance indices across location implied genotypes have different genes controlling yield and stress tolerance indices.

The significant effects of G x L indicated that the genotypes had differential performance over locations for stress indices and the effects of experimental plots with lime and without lime applications also exerted differential effects over locations on the performance of genotypes. Due to the performance inconsistency of genotypes over locations such as with significant effects of G x L interactions, selection of genotypes for superior performance under one set of environment may perform poorly under different. This implies that recommendation of genotypes for all locations and managements of soil acidity is hardly possible based on better performance of genotypes at one location and management. In line with this result previously reported that under significant G x L selection of genotypes that perform best under all sets of environments becomes impractical [31].

Table 4: Mean squares of combined analysis of variance over locations for soil acidity stress indices based on grain yield of 50 faba bean genotypes evaluated with and without lime application in 2017 main cropping season

Trait	Block (6)	Genotype (G) (49)	Location (L) (2)	G x L (98)	Error (294)	CV (%)
YP	376.50	1032.64**	1028.45**	281.20**	87.03	10.02
YS	430.05	572.51**	15788.37**	190.83**	58.96	12.20
RYR$^{\psi}$	0.01	0.04**	2.36**	0.03**	0.00	16.97
SSI$^{\psi}$	0.09	0.99**	46.50**	0.68**	0.08	20.80
YI$^{\psi}$	0.09	0.12**	3.22**	0.04**	0.01	12.23
STI$^{\psi}$	0.43	0.61**	4.28**	0.15**	0.07	21.01
MP(g)	391.44	674.74**	2412.78**	148.32**	63.13	10.18
GMP(g)	404.80	653.45**	4661.11**	148.77**	62.98	10.43
HM(g)	417.88	641.25**	7400.56**	155.91**	63.74	10.76

*and**, significant at P≤0.05 and P≤0.01, respectively. Numbers in parenthesis represent degree of freedom for the respective source of variation. CV (%) = coefficient of variation in percent, YP= yield on lime treated plot (optimum), YS= yield on lime untreated plot (stressed), RYR= relative yield reduction, SSI= stress susceptible index, YI= yield index, STI= stress tolerance index, MP= mean productivity (g), GMP= geometric mean productivity (g), HM= harmonic mean, ψ = unit less trait

3.3 Mean grain yield and soil acidity stress indices of genotypes

The grain yield (YS) of genotypes was ranged between 40.7g (Wayu) and 79.6g (CS20DK) and overall mean of 62.3g under lime free condition (YS). In case of lime untreated, over the three locations, CS20DK, Obse, Wolki, Didia, Dosha, Hachalu, Numan and Moti were high yielder while Wayu was low yielder significantly different from other genotypes (Table 6). On the other hand, the grain yield (YP) of genotypes was ranged between 61.6g (Wayu) and 115.1g (Moti) with the mean value of 93.1g with lime application over the three locations. The genotypes Moti, CS20DK, EKLS/CSR0200104-3 were high yielder whereas Wayu and Holetta-2 were low yielder with significantly different from other genotypes (Table 6). The grain yield of Wayu was the least under both lime levels due to its smaller seed size. CS20DK was high yielder genotype over locations under optimum environments [32].

Jeldu was the lowest and the highest yielding environment without and with lime application, respectively. The grain yield difference with and without lime application indicated the sensitivity of genotypes to soil acidity stress and the growing environment more contributed for grain yield in addition to genotype. Additionally, Jeldu was characterized by the highest values for RYR and SSI while the lowest values for STI, MP and GMP as compared to the three test locations (Table 5). This result was supported by the soil chemical properties of Jeldu before and after lime application (Table 3). In line with this result previously reported that liming significantly increased grain yield of faba bean [33] and 32% yield increment reported in faba bean as a result of lime application [1].

Table 5: Mean grain yield and stress indices performance of the three test locations

Location	YP	YS	RYR	SSI	YI	STI	MP	GMP	HARM
Holetta	92.62^b	69.98^a	0.24^b	1.00^b	1.00^a	1.35^a	81.30^a	80.26^a	0.28^b
Jeldu	95.93^a	51.16^c	0.46^a	1.97^a	0.97^a	1.03^c	73.55^c	69.74^c	0.61^a
WM	90.80^b	67.66^b	0.25^b	1.02^b	0.73^b	1.27^b	79.22^b	78.18^b	0.29^b

YP= optimum yield (limed), YS=stressed yield (without lime), RYR= relative yield reduction, SSI= stress susceptible index, YI= yield index, STI= stress tolerance index, MP= mean productivity (g), GMP= geometric mean productivity (g), HM= harmonic mean

The mean soil acidity stress tolerance index (STI) of genotypes ranged from 0.54 to 1.86 with overall mean value of 1.22. The genotypes Wayu and Holetta-2 had significantly lower, while Moti and CS20DK had significantly higher mean soil acidity stress tolerance index than other genotypes but non-significant difference between mean values of these genotypes. In general, 48% of the genotypes showed lower and higher soil acidity stress tolerance index than the overall mean (Table 6). As reported by Majid *et al*. [34] genotypes with STI values ≥1 possess a higher stress tolerance (STI). Likewise, 82% of the genotypes had STI values ≥1 and identified as soil acidity stress tolerant genotypes.

Stress susceptible index (SSI) varied in the range between 0.48 (Holetta-2) and 2.04 (EK LS/CSR02010-4-3) with the mean values of 1.33 over locations. The genotypes KUSE2-27-33, EH08035-1, EK LS/CSR02017-3-4 and Moti had significantly high SSI from other genotypes. A total of 26 (52%) genotypes had lower stress susceptible index than the overall mean of genotypes (Table 6). The genotypes showed relative yield reduction of 0.17 to 0.43% with a mean value of 0.32% in plots without lime as compared to plots with lime application. Numan and EKLS/CSR02010-4-3 showed significantly lowest and highest yield reduction, respectively. However, other three and eight genotypes also had lower and higher yield reduction, respectively, without significant difference with the mean yield reduction of Numan and EK LS/CSR02010-4-3. Generally, 50% and 48% genotypes showed yield reduction lower and higher than the overall mean yield reduction of genotypes, respectively (Table 6).

Lower values of SSI and RYR with higher values of other evaluated indices indicate better performance of genotypes under stress condition. Therefore, genotypes with low SSI and RYR values were tolerant to soil acidity and that have high values may not perform better under soil acidity condition. Accordingly, genotypes Moti, EKLS/CSR02010-4-3, EH08035-1, KUSE2-27-33 and EKLS/CSR02017-3-4 might not be recommended for areas with soil acidity problem whereas Numan, Holetta-2, Hachalu, Obse, Dosha, Wolki, Gebelcho and NC58 might perform better under acidic soil condition.

The genotypes had mean yield index of 0.90 in the range between 0.58 and 1.14 for Wayu and CS20DK, respectively. CS20DK followed by Moti, Didea, Wolki, Obse, Hachalu, Numan and Dosha had significantly different high yield index than other genotypes while Wayu had significantly lower yield index than mean of other genotypes. A total of 29 (58%) and 21 (42%) genotypes had lower and higher mean YI than overall mean of genotypes, respectively. The genotypes had mean values of 78.02, 76.06 and 74.20g in the range from 51.15 to 96.40, 49.87 to 94.73 and 48.64 to 93.11g in mean productivity (MP), geometric mean productivity (GMP) and harmonic mean (HM) for Wayu and CS20DK, respectively. Genotypes CS20DK and Moti had significantly higher values different than other genotypes. On the other hand, 22 (44%), 23 (46%) and 25 (50%) genotypes had lower MP, GMP and HM than overall mean of genotypes, respectively (Table 6).

In most cases the mean values of genotypes for percent yield reduction and soil acidity tolerance index not coincide with mean values of genotypes for other five soil acidity stress indices. However, Moti and CS20DK had significantly higher YI, MP, GMP and HM. Moti had significantly higher while CS20DK lower mean stress

susceptible index over the three locations. The genotypes EH08035-1, EK LS/CSR02017-3-4 and KUSE2-27-33 had significantly higher yield index which coincides with higher percent yield reduction, but Wolki, Obse, Hachalu and Numan had significantly higher mean yield index as opposed to the significantly lower yield reduction (Table 6).

In general, some genotypes showed similar ranks for two or more soil acidity stress indices. Accordingly, relatively similar ranks of genotypes for STI, GMP and HM were observed. Similar results were reported that genotypes showed relatively identical ranks for MP, HM, GMP and STI [30] for STI, GMP and MP parameters of drought tolerance indices of Turkish oat landraces [35]. Likewise similar patterns of STI and GMP were reported for drought tolerance indices of bread wheat and potato genotypes [36, 37]. Furthermore, genotypes can be categorized as tolerant or susceptible for STI, MP and GMP indices [38]. The authors concluded that parameters that identify genotypes in a similar order were equally important for screening stress tolerant genotypes.

In this study, yield index identified CS20DK, Obse, Wolki, Didi'a, Dosha, Hachalu, Numan and Moti as the best whereas Wayu the least soil acidity adapted genotypes. In most cases, it is rare that the genotypes that had high yield also exhibiting good performance for stress indices. However, CS20DK and Moti had higher mean yield besides showed significantly higher STI, YI, MP, GMP and HM. This suggested that CS20DK and Moti had relatively high grain yield with and without lime application as compared to the other genotypes in spite of the high RYR of Moti. It was reported that genotypes with high STI, MP and GMP values are better yielding under both stress levels [39].

Table 6: Mean performance of seven soil acidity stress indices based on grain yield of 50 faba bean genotypes evaluated with and without lime application at three locations in 2017

No	Genotype	YP	R	YS	R	RYR	R	SSI	R	YI	R	STI	R	MP	R	GMP	R	HM	R
1	Cool-0030	95.93^{c-j}	27	59.31^{i-q}	37	0.36^{d-l}	37	1.61^{b-f}	41	0.85^{j-q}	35	1.14^{g-l}	31	77.63^{d-n}	30	74.62^{h-n}	31	71.82^{i-q}	33
2	Wolki	97.04^{c-j}	26	75.57^{abc}	3	0.24^{u-x}	6	0.94^{q-t}	7	1.08^{abc}	3	1.54^{bcd}	5	86.29^{bcd}	5	84.73^{b-f}	6	83.26^{b-f}	6
3	EK LS/CSR02012-2-3	98.54^{b-g}	18	61.49^{g-o}	29	0.37^{c-j}	39	1.63^{b-f}	42	0.88^{h-o}	27	1.24^{e-k}	24	80.01^{c-n}	24	77.64^{c-n}	23	75.36^{e-o}	23
4	Obse	97.72^{b-i}	22	77.56^{ab}	2	0.20^{wxy}	4	0.89^{rst}	4	1.11^{ab}	2	1.56^{bc}	3	87.63^{bc}	4	86.81^{bc}	3	86.02^{abc}	3
5	NC58	82.22^{k-n}	43	61.64^{g-o}	27	0.25^{s-w}	9	0.91^{q-t}	5	0.88^{h-o}	28	1.03^{j-n}	39	71.93^{m-r}	42	70.88^{m-q}	39	69.87^{l-r}	37
6	Ashebeka	98.81^{b-g}	16	69.34^{b-h}	12	0.30^{l-u}	18	1.30^{g-o}	26	0.99^{b-i}	12	1.40^{c-g}	10	84.06^{c-g}	13	82.52^{c-i}	10	81.02^{b-i}	10
7	Hachalu	89.73^{e-k}	32	72.91^{a-e}	6	0.19^{xy}	3	0.74^{t}	2	1.04^{a-e}	6	1.35^{c-i}	18	81.31^{c-l}	21	80.82^{c-k}	18	80.34^{b-j}	11
8	Degaga	87.26^{i-m}	38	59.62^{i-q}	36	0.31^{i-r}	23	1.22^{j-q}	21	0.85^{j-q}	36	1.07^{i-n}	37	73.44^{j-q}	38	71.77^{k-p}	37	70.17^{k-r}	36
9	EH09031-4	88.60^{g-l}	36	61.60^{g-o}	28	0.31^{k-s}	21	1.19^{l-r}	19	0.88^{h-o}	29	1.13^{g-m}	33	75.08^{g-p}	35	73.69^{i-o}	33	72.34^{h-q}	32
10	Holetta-2	64.01^{o}	49	53.25^{n-r}	45	0.18^{y}	2	0.48^{u}	1	0.76^{n-r}	45	0.71^{op}	49	58.62^{t}	49	58.22^{s}	49	57.84^{u}	49
11	EH09007-4	89.34^{e-k}	33	54.77^{l-r}	42	0.38^{a-h}	43	1.52^{c-j}	35	0.78^{m-r}	42	1.00^{j-n}	42	72.05^{m-r}	41	69.44^{n-r}	41	67.00^{n-t}	42
12	EH07023-3	102.63^{bc}	5	65.74^{d-k}	19	0.34^{e-m}	32	1.63^{b-f}	40	0.94^{d-l}	19	1.37^{c-h}	16	84.18^{c-g}	12	81.78^{c-j}	12	79.49^{c-j}	15
13	EK05006-3	99.06^{b-g}	15	70.01^{b-g}	11	0.27^{p-v}	11	1.28^{h-o}	24	1.00^{b-h}	11	1.40^{c-h}	11	84.53^{c-f}	11	82.21^{c-j}	11	80.01^{b-j}	12
14	EK LS/CSR02014-2-4	88.99^{f-l}	35	62.76^{f-l}	22	0.28^{n-v}	13	1.16^{m-r}	17	0.90^{f-m}	22	1.14^{g-l}	32	75.87^{f-p}	32	74.42^{h-o}	32	73.02^{h-p}	30
15	Numan	91.34^{d-k}	31	72.75^{a-e}	7	0.17^{y}	1	0.82st	3	1.04^{a-e}	7	1.34^{c-i}	19	82.04^{c-j}	19	80.64^{c-l}	19	79.32^{c-k}	18
16	Bulga 70	89.13^{e-l}	34	55.36^{l-r}	40	0.38^{a-i}	42	1.49^{d-l}	31	0.79^{m-r}	40	1.02^{j-n}	40	72.24^{l-q}	40	69.06^{n-r}	42	66.26^{o-u}	43
17	EK05001-1	87.75^{h-m}	37	62.60^{f-m}	23	0.25^{r-v}	8	1.11^{n-s}	13	0.89^{f-m}	23	1.10^{h-m}	35	75.16^{g-p}	34	73.19^{j-o}	34	71.35^{j-q}	35
18	Dosha	98.07^{b-h}	21	74.05^{a-d}	5	0.23^{vwx}	5	1.06^{n-s}	10	1.06^{a-d}	4	1.48^{b-e}	6	86.04^{bcd}	7	84.86^{b-e}	5	83.71^{b-e}	5
19	Gora	99.94^{b-e}	11	70.99^{b-f}	9	0.28^{n-v}	14	1.27^{h-o}	23	1.01^{b-f}	9	1.45^{b-f}	8	85.45^{bcd}	9	83.97^{b-g}	8	82.52^{b-g}	8
20	EH08035-1	99.33^{b-g}	13	57.68^{j-r}	38	0.43^{abc}	48	1.83^{abc}	48	0.82^{k-r}	38	1.19^{e-k}	28	78.51^{c-n}	28	75.47^{f-n}	29	72.57^{h-q}	31
21	Wayu	61.60^{o}	50	40.72^{s}	50	0.35^{e-l}	35	0.92^{q-t}	6	0.58^{s}	50	0.54^{p}	50	51.15^{u}	50	49.87^{t}	50	48.64^{v}	50
22	EK LS/CSR02023-2-1	91.48^{d-k}	30	53.76^{m-r}	44	0.41^{a-d}	47	1.66^{b-e}	43	0.77^{m-r}	44	1.01^{j-n}	41	72.62^{k-q}	39	69.91^{m-q}	40	67.34^{n-t}	40
23	Mesay	78.83^{lmn}	45	55.17^{l-r}	41	0.29^{l-v}	16	1.04^{o-s}	9	0.79^{m-r}	41	0.89^{l-o}	44	66.99^{p-s}	45	65.65^{o-s}	44	64.36^{p-u}	44
24	EH09004-2	99.19^{b-g}	14	60.16^{i-q}	32	0.40^{a-e}	46	1.72^{bcd}	45	0.86^{j-q}	32	1.28^{c-k}	22	79.67^{c-n}	25	77.0^{d-n}	25	74.45^{f-o}	24

25	EH06088-6	95.87^{c-j}	29	60.01^{i-q}	33	0.37^{b-j}	40	1.58^{b-i}	37	0.86^{j-q}	33	1.18^{f-k}	30	77.93^{d-n}	29	75.73^{e-n}	28	73.59^{g-o}	29
	Mean	93.13		62.93		0.32		1.33		0.90		1.22		78.02		76.06		74.20	
	Min	61.60		40.72		0.17		0.48		0.58		0.54		51.15		49.87		48.64	
	Max	115.10		79.56		0.43		2.04		1.14		1.86		96.4		94.73		93.11	

Mean values of the same category followed by different letters are significant at p ≤0.05 level, YP= optimum yield (limed), YS=stressed yield (without lime), RYR= relative yield reduction, SSI= stress suseptible index, YI=yield index, STI =soil acidity tolerance index, MP= mean productivity, GMP= geometric mean productivity, HM= harmonic mean, R= rank of genotypes

No	Genotype	YP	R	YS	R	RYR	R	SSI	R	YI	R	STI	R	MP	R	GMP	R	HM	R
26	EK LS/CSR02017-3-4	101.08^{bcd}	7	59.70^{i-q}	35	0.40^{a-f}	45	1.82^{abc}	46	0.85^{j-q}	37	1.22^{e-k}	26	80.38^{c-m}	23	77.14^{d-n}	24	74.12^{f-o}	27
27	Kasa	75.73^{n}	47	51.43^{qr}	48	0.32^{h-q}	26	1.07^{n-s}	11	0.73^{qr}	48	0.80^{no}	47	63.59^{rst}	47	62.24^{qrs}	47	60.94^{stu}	47
28	Cool-0025	98.50^{b-g}	19	62.48^{f-m}	24	0.36^{d-k}	38	1.59^{b-h}	38	0.89^{f-m}	24	1.26^{d-k}	23	80.48^{c-m}	22	78.00^{c-n}	22	75.65^{d-n}	22
29	EH06070-3	84.47^{k-n}	42	57.25^{k-r}	39	0.31^{j-r}	22	1.20^{k-r}	20	0.82^{l-r}	39	0.99^{k-n}	43	70.85^{n-r}	43	68.98^{n-r}	43	67.22^{n-t}	41
30	EK LS/CSR02010-4-3	108.47^{ab}	3	62.03^{g-n}	26	0.43^{a}	50	2.04^{a}	50	0.89^{g-n}	25	1.39^{c-h}	13	85.24^{cde}	10	81.77^{c-j}	13	78.48^{c-m}	20
31	Cool-0031	98.42^{b-h}	20	59.93^{i-q}	34	0.39^{a-g}	44	1.69^{bcd}	44	0.86^{j-q}	34	1.22^{e-k}	25	79.17^{c-n}	27	76.60^{e-n}	27	74.14^{f-o}	26
32	Cool-0018	97.68^{b-i}	24	61.46^{g-o}	30	0.35^{d-l}	36	1.60^{b-g}	39	0.88^{h-o}	30	1.21^{e-k}	27	79.56^{c-n}	26	76.66^{e-n}	26	73.97^{f-o}	28
33	EK LS/CSR02028-1-1	98.71^{b-g}	17	64.78^{e-k}	21	0.32^{i-q}	25	1.49^{d-l}	32	0.93^{e-l}	20	1.29^{c-j}	21	81.73^{c-k}	20	78.78^{c-m}	21	76.12^{d-n}	21
34	EK 05037-4	100.87^{bcd}	8	66.76^{d-i}	16	0.34^{g-o}	30	1.50^{d}-^{l}	33	0.95^{d-j}	16	1.38^{c-h}	14	83.82^{c-g}	14	81.62^{c-j}	14	79.53^{c-j}	14
35	Cool-0035	97.36^{c-j}	25	68.21^{c-i}	13	0.30^{k-t}	19	1.28^{g-o}	25	0.97^{c-j}	13	1.37^{c-h}	17	82.78^{c-i}	17	81.08^{c-j}	17	79.44^{c-j}	16
36	KUSE2-27-33	95.90^{c-j}	28	54.45^{l-r}	43	0.43^{ab}	49	1.83^{abc}	47	0.78^{m-r}	43	1.07^{i-n}	36	75.18^{g-p}	33	71.78^{k-p}	36	68.63^{n-s}	39
37	EH07015-7	100.64^{bcd}	10	66.34^{d-j}	18	0.35^{e-l}	33	1.51^{d-k}	34	0.95^{d-k}	17	1.39^{c-h}	12	83.48^{c-h}	15	81.42^{c-j}	16	79.44^{c-j}	17
38	Cool-0024	103.25^{bc}	4	68.02^{c-i}	14	0.34^{f-n}	31	1.55^{c-i}	36	0.97^{c-j}	14	1.45^{c-f}	9	85.63^{bcd}	8	83.40^{b-h}	9	81.27^{b-h}	9
39	Selale	74.91^{n}	48	50.08^{r}	49	0.32^{i-q}	27	1.09^{n-s}	14	0.72^{r}	49	0.79^{no}	48	62.49st	48	61.05^{rs}	48	59.65^{tu}	48
40	Moti	115.10^{a}	1	72.74^{a-e}	8	0.37^{b-j}	41	1.86^{ab}	49	1.04^{a-e}	8	1.72^{ab}	2	93.92^{ab}	2	91.22^{ab}	2	88.63^{ab}	2
41	EH06027-2	86.75^{j-m}	41	62.09^{g-n}	25	0.28^{m-v}	15	1.09^{n-s}	12	0.89^{g-n}	26	1.11^{g-m}	34	74.42^{h-p}	36	73.08^{j-o}	35	71.79^{i-q}	34
42	EK LS/CSR02019-2-4	97.71^{b-i}	23	66.65^{d-i}	17	0.31^{i-r}	24	1.37^{e-n}	28	0.95^{d-j}	18	1.34^{c-i}	20	82.17^{c-j}	18	80.54^{c-l}	20	78.96^{c-l}	19
43	EH09002-1	86.77^{j-m}	40	60.86^{h-p}	31	0.28^{o-v}	12	1.14^{m-r}	16	0.87^{i-p}	31	1.07^{i-n}	38	73.81^{i-p}	37	71.60^{l-p}	38	69.58^{m-s}	38
44	Tumsa	101.22^{bcd}	6	70.91^{b-f}	10	0.29^{l-v}	17	1.33^{f-o}	27	1.01^{b-g}	10	1.47^{b-f}	7	86.06^{bcd}	6	84.33^{b-g}	7	82.67^{b-g}	7

45	Gebelcho	86.92^{j-m}	39	65.22^{e-k}	20	0.24^{t-x}	7	0.96^{p-t}	8	0.93^{e-l}	21	1.18^{f-k}	29	76.06^{e-o}	31	75.23^{g-n}	30	74.41^{f-o}	25
46	EK05037-5	81.75^{k-n}	44	52.96^{o-r}	46	0.35^{d-l}	34	1.27^{i-p}	22	0.76^{o-r}	46	0.88^{l-o}	45	67.35^{o-s}	44	65.50^{o-s}	45	63.75^{q-u}	45
47	Didi'a	100.84^{bcd}	9	74.49^{a-d}	4	0.26^{q-v}	10	1.16^{m-r}	18	1.06^{a-d}	5	1.55^{bcd}	4	87.66^{bc}	3	86.14^{bcd}	4	84.68^{bcd}	4
48	Cool-0034	99.75^{b-f}	12	67.04^{c-i}	15	0.33^{h-p}	29	1.44^{d-m}	29	0.96^{c-j}	15	1.37^{c-h}	15	83.39^{c-h}	16	81.48^{c-j}	15	79.64^{c-j}	13
49	CS20DK	113.24^{a}	2	79.56^{a}	1	0.30^{k-t}	20	1.48^{d-l}	30	1.14^{a}	1	1.86^{a}	1	96.40^{a}	1	94.73^{a}	1	93.11^{a}	1
50	Tesfa	77.81^{mn}	46	52.31^{pqr}	47	0.32^{h-q}	28	1.12^{n-s}	15	0.75^{pqr}	47	0.85^{mno}	46	65.06^{q-t}	46	63.73^{p-s}	46	62.43^{r-u}	46
	Mean	93.13		62.93		0.32		1.33		0.90		1.22		78.02		76.06		74.20	
	Min	61.60		40.72		0.17		0.48		0.58		0.54		51.15		49.87		48.64	
	Max	115.10		79.56		0.43		2.04		1.14		1.86		96.4		94.73		93.11	

Mean values of the same category followed by different letters are significant at $p \leq 0.05$ level, YP= optimum yield (limed), YS=stressed yield (without lime), RYR= relative yield reduction, SSI= stress suseptible index, YI=yield index, STI =soil acidity tolerance index, MP= mean productivity, GMP= geometric mean productivity, HM= harmonic mean, R= rank of genotypes

Moreover, to determine the most desirable soil acidity stress tolerant genotype based on multiple indices, the rank mean, standard deviation of ranks and rank sum of all used soil acidity stress tolerance indices was calculated. Accordingly, genotypes Obse, Wolki, Dsha, Didea and Gora were selected the most soil acidity stress tolerant genotypes having the best rank mean, low standard deviation of ranks, and smaller rank sum. Likewise, the rank mean, standard deviation of ranks and rank sum identified Wayu, Selale, Kasa, Tesfa and Holetta-2 as the most sensitive genotypes to soil acidity stress (Table 7).

Table 7: Top five most tolerant and susceptible genotypes based on rank sum of indices

Genotype	YP (g/5plants)	YS (g/5plants)	RM	SDR	RS	Rank	Remark
Obse	97.7	77.6	3.3	0.8	4.0	50	Tolerant
Wolki	97.0	75.6	5.4	1.3	6.7	49	Tolerant
Dosha	98.1	74.1	6.0	2.0	8.0	48	Tolerant
Didi'a	100.8	74.5	6.9	5.4	12.3	47	Tolerant
Gora	99.9	71.0	11.3	5.6	16.9	46	Tolerant
Wayu	61.6	40.7	41.6	16.7	58.2	1	Susceptible
Selale	64.0	53.3	34.9	22.8	57.7	2	Susceptible
Kasa	74.9	50.1	40.3	14.0	54.3	3	Susceptible
Tesfa	75.7	51.4	39.0	14.7	53.7	4	Susceptible
Holetta-2	77.8	52.3	39.1	12.6	51.8	5	Susceptible

YP= optimum yield (limed), YS=stressed yield (without lime), RM= rank mean, SDR=standard deviation of ranks, RS= rank sum

Generally, based on the values of multiple indices, rank sum of indices and performance of grain yield under stressed and non-stressed environments genotypes Obse, Wolki, and, Dosha were identified as the most desirable soil acidity tolerant genotypes whereas Wayu and Holetta-2 were identified as the most sensitive genotypes. Moreover, the great variability of the 50 faba bean genotypes exhibited a good potential to screening large germplasm of faba bean for soil acidity tolerance and develop a cultivar that are tolerant to soil acidity in the country. It is possible to conclude that SSI and STI have inverse relationship and genotypes with high SSI mean that genotypes have low STI value. Likewise such value will have by default high RYR and low MP, GMP and HM.

3.4 Association of stress indices

3.4.1 Correlation among soil acidity stress tolerance indices

To determine the most desirable soil acidity stress tolerance indices correlation coefficients between yield under lime free condition (YS) and limed condition (YP) and other quantitative stress tolerance indices were presented in Table 8. The correlation coefficient (r=0.71) among YS and YP cannot completely guarantee that high potential yield under optimum conditions results in improved yield under stress (lime free) condition. Hence, indirect selection for a soil acidity-prone environment based on the results of optimum conditions will not be efficient. As stated by Mitra [40] a suitable index must have a significant correlation with grain yield under both lime conditions.

The grain yield under lime treated plots (YP) was positive and significantly correlated with YS and all soil acidity stress indices. Likewise, YS showed a positive significant correlation with YI, STI, MP, GMP and HM whereas a negative significant association with SSI and RYR which is in agreement with Gholipouri *et al.* [41] who studied the relationship of drought resistance indices with grain yield of bread wheat cultivars and reported a highly negative association of YS with SSI index. Similarly, Zerihun [37] found a significant negative association of YS with SSI during evaluating potato genotypes for drought tolerance. Furthermore, this result partially agrees with Sabaghnia and Janmohammadi [38] who reported a non-significant negative and positive association of YS with SSI and RYR, respectively. Therefore, SSI and RYR indices are suitable to identify genotypes with low yield and susceptible to soil acidity because under stress condition (without lime) yield decreased with increasing SSI and RYR. Moreover, YI, STI, GMP, MP and HM exhibited a strong

and positive correlation with both YP and YS, suggesting that these traits are suitable to discriminate soil acidity tolerant genotypes with high grain yield both with and without lime treated environmental conditions. Similarly, Zerihun [37] found a strong and positive association of YI, STI, GMP, MP and HM with both YS and YP and used as suitable indices to differentiate stress resistant genotypes.

The GMP index had strongly positive association with YI, STI, MP and HM amongst each other which is in accordance with the finding of Javed *et al.* [30] and Zerihun [37]. A negative correlation was found for YI with RYR. Generally, all the evaluated stress indices were significantly correlated with both grain yields (YP and YS) except YS with SSI. This result allowed concluding that the evaluated stress indices were suitable to identify faba bean genotypes susceptible or tolerant to soil acidity stress.

Table 8: Correlation of soil acidity tolerance indices and grain yield of faba bean with and without lime treated environments in 2017

	YP	YS	SSI	RYR	YI	STI	MP	GMP
YS	**0.71****							
SSI	0.67**	-0.05						
RYR	0.28*	-0.46**	0.89**					
YI	0.71**	**1.00****	-0.05	-0.46**				
STI	0.90**	0.93*	0.29*	-0.12	0.93**			
MP	0.95**	0.90**	0.39**	-0.04	0.90**	0.99**		
GMP	0.92**	0.93**	0.32*	-0.11	0.93**	0.99**	1.00**	
HM	0.88**	0.95**	0.24	-0.18	0.96**	0.99^{**}	0.99**	1.00**

YP= optimum yield (limed), YS=stressed yield (without lime), SSI= soil acidity susceptible index, RYR= relative yield reduction, YI= yield index, STI= soil acidity tolerance index, MP= mean productivity (g), GMP= geometric mean productivity (g), HM= harmonic mean

IV. CONCLUTION

The genotypes with high STI, MP and GMP values considered as better yielding under both stress levels. Accordingly, genotype CS20DK had relatively high grain yield with and without lime application as compared to the other genotypes. The multiple stress indices (YI, STI, MP, GMP, HM, SSI and RYR) confirmed Wolki, Dosha, and Obse as the most desirable soil acidity tolerant genotypes whereas Wayu was identified as the most sensitive genotype.

The correlation showed YS was strongly correlated with YI indicating that YS can discriminate soil acidity stress tolerant genotypes with high grain yield under stress conditions. Accordingly, CS20DK, Obse, Wolki, Didi'a and Dosha were the top 5 high yielding cultivars under stress environments, respectively. Additionally, CS20DK have uniform superiority under both stress and limed condition which is an asset (113.24 g/5plants at non-stressed and 79.56 g/5plants). However, lack of consistency in rank orders of genotypes among the stress indices in discriminating the tolerant and susceptible genotypes in this study implies use of multiple stress indices instead of single index selection of soil acidity tolerant genotypes in faba bean. The great variability of the 50 faba bean genotypes exhibited a good potential to screening large germplasm of faba bean for soil acidity stress tolerance and develop a tolerant cultivar. Moreover, for successful recommendation of genotypes for commercial production for farmers with soil acidity prone areas of Ethiopia, it needs to validate in more locations over years and with all possible stress indices.

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